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High Energy Density Plasma Experiments of Interest to Astrophysics

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John I. Castor
Lawrence Livermore National Laboratory
Livermore, CA 94550, U.S.A.

Material in the universe exists in an enormous range of physical conditions—from hundreds of millions of degrees kelvin in the centers of some stars and in the central engines of quasars to just a few degrees kelvin in the interiors of dense interstellar clouds; from the density of nuclear matter to less than one particle per cubic centimeter. Most of our astrophysical understanding has necessarily been based on physical theory, since these conditions are so far from those that can be realized in the laboratory. Yet in recent years the advent of high power lasers and other plasma machines has opened up some of these extreme regimes to direct experimentation. Specifically, matter can now be studied at temperatures up to about 1 keV (10^7 K), and at densities from air density or less up to perhaps 10^3 grams/cm^3, using high power lasers. These conditions overlap well with those that are found in stellar envelopes, and are also not too far from conditions thought to have existed in the Big Bang. It is not necessary to literally make a star to perform astrophysical experiments; the physical processes that govern how the star works can be abstracted and studied by themselves in the laboratory. These are such processes as the absorption of radiation by stellar material, the pressure-energy-density-temperature relations in the plasma, and the rates of the thermonuclear reactions that provide energy and transmute the chemical elements within the star. Other processes have an intermediate length scale between the atoms and nuclei on the one hand and the whole star on the other hand, such as turbulent mixing and energy transport. Astrophysicists use rather simple models of these mesoscale processes, which can be tested in laboratory experiments. Some highlights of the astrophysical experiments that have already been done will be reviewed, and a few ideas for future experiments will be discussed.

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